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(54) Arrangement for shaping and redirecting radiation

(57) Arrangement for shaping and redirecting radiation of at least n linear laser-diode arrays whose beam-emission apertures run in the direction lying in the x-z-plane and whose ray bundles are directed in the x-z-plane using imaging optics and are redirected by optical elements under a specified beam angle whereby m optical elements are stacked in planes on top of one

another in the y-direction forming a unit, whereby the x-, y- and z-directions constitute an orthogonal coordinate system and n, m are positive integers that are characterized in that at least m = (n-l) of the optical elements are provided, where $n \geq 3$ and l is the integral part of the quotient n/k, whose deflection surfaces, when projected on a common plane in the x-z-plane, are oriented at an angle to one another, that the three or more laser-diode arrays stacked in consecutive planes in the y-direction are combined into a unit of k laser-diode arrays where k is a positive integer and $3 \leq k \leq n$ and whereby the first optical element is assigned to the first laser-diode array of the unit, the second optical element of the unit is assigned to the second laser-diode array and so forth until the (k-1)'st optical element is assigned to the (k-1)'st laser-diode array and the elements deflect the beams on the deflection surfaces into an essentially common beam direction and the k'th...

Description

The present invention concerns an arrangement for shaping and redirecting radiation from at least n linear laser-diode arrays whose beam-emission apertures run in the direction lying in the x-z-plane and whose ray bundles are directed in the x-z-plane using imaging optics and are redirected by optical elements under a specified beam angle whereby m optical elements are stacked in planes on top of one another in the y-direction forming a unit, whereby the x-, y- and z-directions constitute an orthogonal coordinate system and n, m are positive integers.

An arrangement of the type described above is, for example, known in the art from DE A1 44 38 368.

Laser diodes, also called semiconductor lasers, are increasingly applied in many areas, for example, for optical pumping of solid-state lasers or for material processing. The output of the laser diodes required for these uses extend from a few 100 W up to the kilowatt range. In order to scale laser diodes to high output, a number of laser diodes are combined into one- or two-dimensional laser-diode arrays or field arrangements in order to sum the laser outputs of the individual laser diodes.

High-output laser diodes have a strongly asymmetric beam distribution. With laser-diode bars (a one-dimensional, linear laser-diode array) the outer dimensions of the emission aperture at laser discharge are about 0.001 mm x 10 mm and the beam divergence is around ($30^{\circ}...50^{\circ}$) x 5° (perpendicular x parallel to the pn-transition plane; the numbers cited are the half flair angles defined by the $1/e^2$ falloff of beam intensity). Typical dimensions of laser-diode bars are 10 mm x 0.6 mm x 0.1 mm (width x depth x height). In order to sum the beams of the individual laser diodes of the laser-diode array, it is advantageous to have the beam-emission apertures of the individual laser diodes lying very close to one

another in the plane so that a compact arrangement can be achieved. A limiting factor in this, however, is having sufficient cooling of the individual laser diodes or laser-diode bars, to which end they are mounted on appropriate heat sinks. As heat sinks, for example, microchannel coolers made of silicon or copper are used, which are actively cooled by means of a cooling fluid that flows through the microchannel structure of the microchannel cooler. Typical dimensions of such heat sinks are, for example, a cross-sectional area of about 12 mm x 20 mm (width x depth) and a height in the range of 1...10 mm. This means that the height of the heat sink is markedly greater than the height of the mounted laser-diode bars.

As has already been alluded to above, a known method for summing beams of laser-diode bars is the linear stacking arrangement. For this purpose, the laser diodes, each of which is mounted on a heat sink, are arranged one on top of another so that the pn-transition plans of the individual laser diodes are oriented as parallel as possible to one another. Such linear stacking arrangements are employed, for example, for optical pumps for rectangular laser media in so-called laser-bar configuration. In this case, the pump light is irradiated over a large area through the side surfaces of the laser medium. A strong focusing of the beam is not necessary here. A focusing of the beam is, however, necessary when high radiation density (radiation power per area and solid angle, W/m^2sr) and/or a small cross-sectional area of the beam is required. In this case, beam shaping of the laser-diode beam is necessary. For this beam shaping, in front of each laser-diode bar, a cylindrical collimation optic is mounted, which collimates the beam in the strongly divergent direction. In order to achieve the highest possible packing density, the heat sinks with mounted laser diodes and the collimation optics must have a very small height and be packed very tightly on one another. But with diminished height, and thereby size of the heat sinks, their cooling capacity is decreased and the required fabrication effort increases. In the case where the cooling capacity is not sufficient, this can lead to a deficiency in the structural area, which carries over to a negative effect

on the mounted laser diodes and can then lead to maladjustments. Therefore, the demand for a high packing density of the laser-diode bars is counteractive to the demand for an optimal construction of the heat sinks.

Another demand in using individual laser-diode bars to scale laser diodes to high output densities is that the ray bundles given off by the laser diodes arranged on top of one another have as small a separation between them as possible. This means that the cylindrical collimation elements must be arranged very tightly on one another, whereby a very precise simultaneous positioning is required. This decreases the allowable tolerances for the lens dimension and, under given fabrication tolerances, leads to the situation that, after a certain number of laser diodes are arranged on top of one another, a positioning of the collimation elements is no longer possible. As a result, for given separation distances, the number of laser diodes and the maximum beam capacity of the stacking arrangement are limited. In addition, collimation optics must be used and illuminated up to the edge. As a result, the influences on optical quality in the edge region of the collimation optics as well as undesired bending effects at the sharply limited lens aperture must be taking into account.

A further disadvantage of this stacking arrangement, as it has been presented above, is the unsymmetrical beam distribution. For an assumed separation of the laser diodes of only 2 mm, for 100 laser diodes, there is an emission aperture of about 10 mm x 200 mm. This requires, for subsequent beam shaping, comparably large diameters for the optical elements, as for example lenses, and is thereby associated with comparably high fabrication errors and costs.

In addition, and arrangement for splitting a laser beam of high output into two or four individual beams is known from DE A1 44 38 368. The light beams lie in a common plane and describe an angle of 90° to one another.

Based on the state of the art described in the introduction as well as the problems of beam summation of individual laser diodes given above, the present invention is based on the task of creating an arrangement for shaping and

redirecting radiation from at least n linear laser-diode arrays or laser-diode bars that can be compactly built into a tightly limited space without thereby restricting the cooling efficiency of the complete arrangement and that avoids the further existing problems.

The current task is solved by an arrangement with the characteristics listed in the introduction in that at least m = (n-l) of the optical elements are provided, where $n \geq 3$ and l is the integral part of the quotient n/k, whose deflection surfaces, when projected on a common plane in the x-z-plane, are oriented at an angle to one another, that the three or more laser-diode arrays stacked in consecutive planes in the y-direction are combined into a unit of k laser-diode arrays where k is a positive integer and $3 \leq k \leq n$ and whereby the first optical element is assigned to the first laser-diode array of the unit, the second optical element of the unit is assigned to the second laser-diode array and so forth until the (k-1)'st optical element is assigned to the (k-1)'st laser-diode array and the elements deflect the beams on the deflection surfaces into an essentially common beam direction and the k'th laser-diode array radiates directly or undeflected through a further optical element in the final beam direction so that the beam segments, at least in one imaging plane, are combined into an essentially common beam direction and that the sequence of planes as regards the ordering of the respective laser-diode arrays and their associated respective optical elements in the y-direction above and/or below the unit by more than k planes recapitulates the sequence of the plans of the unit.

The arrangement according to the invention has the advantage that the laser-diode arrays are arranged alternately in planes on top of one another in such a way that sufficient space remains to position the respective cooling bodies as well as the imaging optics so that these components have no interfering influence on the neighboring planes immediately above one another since, seen in projection on one another perpendicular to the planes, one of the first planes corresponding to the orienting of the respective laser-diode arrays repeats itself only in each k'th plane. As a result, sufficient free space remains to give the

cooling bodies, which are assigned to each of the laser-diode arrays, sufficiently large dimensions to achieve effective cooling. In addition, there is sufficient space for the collimation optics to give them large enough dimensions that the edge zones do not have to be used and imaging errors, as explained above in the context of the discussion on the state of the art, can be avoided. Via the respective optical elements or deflection surfaces corresponding to each of the laser-diode arrays, the respective ray bundles are redirected in a direction that essentially corresponds to a direction in which one laser-diode array of the unit consisting of at least three laser-diode arrays radiates directly. This means that in a unit, which consists of k planes, whereby each plane corresponds to a respective laser-diode array, one of these laser-diode arrays radiates directly without a beam deflection while the radiation of the (k-1) other laser-diode arrays are deflected into this beam direction. In order to expand such a base unit consisting of k laser-diode arrays arranged in k planes with a further laser-diode array in an additional plane, the sequence is maintained that corresponds to the sequence in this unit consisting of k planes so that the laser-diode array of this additional plane, seen in a projection orthogonal to the respective planes, is positioned in an area that corresponds to the k'th plane above it or below it, depending on which side this additional plane is appended to. It is obvious that the laser-diode arrays of the individual planes, when the basic unit is constructed from k such planes, are then arranged at k different places of the respective planes, for example, based on a square or rectangular geometry, on three sides of these fictitious squares or rectangles while the beam emerges in the direction of the fourth side. Other units based on this principle according to the invention are possible that are based on an arrangement geometry of the laser-diode arrays in the form of a polygon with more than four sides, whereby a laser-diode array is assigned alternately to each individual side of such a polygon, one plane on top of another, until each respective side, except for one side, from which the beam emerges, is assigned one such laser-diode array and the sequence, beginning with the laser-diode array of the first plane, is repeated.

Based on the principle as it was explained above, a preferred possibility for deflecting the beam component in the respective planes and yet maintaining a compact construction of the arrangement given thereby is that the deflection surfaces be formed by edges of prism plates. In these plates, the beam enters from one side-edge and is deflected on mirrored plane edges. The surfaces deflecting the beam can, however, also be formed by mirrored surfaces of other bodies, preferably plate-shaped pieces. Such prism plates each have, in a preferred embodiment, the form of a right triangle in the x-z-plane. These prism plates, in a further advantageous arrangement, are each oriented in the planes one on top of another with their deflection surfaces in such a way that the deflection surfaces, viewed in the y-direction, i.e. orthogonal to the respective planes, are oriented at an angle of about 90° to one another. In such a case, radiation would then enter from two opposite sides, when all planes in projection on one another are observed, while on the third side, which then lies at an angle of 90° to these two sides, the beam emitted by the corresponding laser-diode array is essentially not deflected. This is the direction then into which the radiation from the laser-diode arrays in the planes above and below this one is redirected by the deflection surfaces.

An analogous arrangement to the one explained above arises from the use of mirrored surfaces that redirect each of the beam segments. Such mirrored surfaces can be applied to respective molded bodies, for example, on an edge of a plate-shaped molded body, whereby positioning is simple. The radiation of the third laser-diode array, in the case where the laser-diode arrays are arranged in three planes, is transmitted through a free space with only collimation. A further measure that simplifies positioning is possible when a rectangular plate is placed in this free space, which simultaneously serves as positioning surface for the preferably plate-shaped deflection elements in the planes above and below it and through which the radiation passes with essentially no influence on the beam path.

In order to reduce positioning expenditure for the arrangement further to a minimum, the optical elements can be formed from a block or from blocks, where the various free spaces through which the laser-diode radiation passes undeflected can be formed by appropriate recesses, for example slits or other cutouts in the block while the deflection surfaces are mirrored surfaces of the block or blocks.

Further details and characteristics of the invention are given in the following description of three embodiments with the use of figures.

The three embodiments, as they are presented in the figures, serve to illustrate various basic principles as well as basic structures of the invention.

It shows:

Fig. 1 a schematic side view of the first embodiments of the arrangement for shaping and redirecting radiation of a number of laser-diode arrays through the use of prism plates and angle plates in the individual planes, and specifically, as viewed along the perspective arrow II in Fig. 2,

Fig. 2 a top view of the arrangement in Fig. 1 as viewed along the perspective arrow I in Fig. 1,

Fig. 3 a top view of an arrangement according to a second embodiment, which, instead of individual prism plates, uses various prisms fabricated from one block,

Fig. 4 a top view of the deflection surfaces of prisms of Fig. 3 as viewed along the perspective arrow IV in Fig. 3,

Fig. 5 a top view of an arrangement according to a third embodiment, which uses a single prism block with mirrored deflection surfaces and free spaces or slits and

Fig. 6 a schematic view of the prism block of Fig. 5 as viewed along the perspective arrow VI in Fig. 5.

To begin, the first embodiment of the arrangement for shaping and redirecting radiation from linear laser-diode arrays is described. The arrangement, as it is presented in Fig. 1, is presented as seen against the

emerging laser radiation (4) (see Fig. 2), i.e. from the direction of the perspective arrow II in Fig. 2.

The base unit from which the arrangement, as it is presented in Fig. 1 and 2, is built comprises a first prism plate (1), a rectangular plate (2) and a second prism plate (3). The respective plates (1, 2 and 3) are oriented in an x-z-plane and stacked one on top of the other in the y-direction as given by the respective coordinate axes (x, y and z) in Fig. 1 and Fig. 2. The rectangular plate (2) has a square shape, as can be recognized in Fig. 2, whereas the two triangular prism plates (1 and 3) have the shaped of an isosceles right triangle in the overhead view. The lengths of the legs (5) of these prism plates (1, 3) agree essentially with the edge length of the square rectangular plate (2). The respective hypotenuse sides (7) of the first prism plate (1) and the second prism plate (3) of each unit are mirrored and form reflection or deflection surfaces (6), which, in projection on each other in the y-direction, are oriented at an angle (8) of 90° to one another. The rectangular plate (2) consists of a material that is transparent for the wavelength of the laser radiation, such as, for example, glass in the visible wavelength range or in the near infrared range. Alternatively, the rectangular plate (2) can be replaced by a free space and spacing elements positioned outside of the free space where the radiation passes.

As is made clear by considering Fig. 1 and 2 together, a linear laser-diode array (9.1, 9.2 and 9.3) with extension in the x-z-plane is assigned to each prism plate (1, 3) and each rectangular plate (2). The laser-diode arrays (9.1, 9.2 and 9.3) are each mounted on a cooling body (10). Furthermore, to each laser-diode array (9.1, 9.2 and 9.3) there is a collimation optic (11) assigned and specifically in the embodiments, as shown in the figures, in the form of a cylindrical lens, in order to guide the laser-diode beams predominately collimated onto the deflection surfaces (6) of the respective prism plates (1, 3) facing it.

As is obvious from considering Fig. 1 and 2 together, the respective laser-diode arrays (9.1, 9.2 and 9.3) are matched with the deflection surface (6) of the first prism plate (1), the facing (12) of the rectangular plate (2) and the deflection

surface (6) of the second prism plate (3), which represent a unit and are distributed sequentially around the three sides. When adding on to this unit, this order of the arrangement of the respective laser-diode arrays (9.1, 9.2 and 9.3), the first prism plate (1), the rectangular plate (2) and the second prism plate (3) is repeated in the subsequent planes. By this alternating arrangement of the laser-diode arrays (9.1, 9.2 and 9.3), the separation between neighboring cooling bodies (10), given by h_{DL} in Fig. 1, corresponding to three times the overall height, h_{FE} seen in the y-direction, of the respective prisms and rectangular plates (1, 2 and 3) can be employed without having the cooling bodies (10) disturbing one another. In this way, all of the available room around the arrangement, with respect to the three sides of the square or rectangular projected base area, is utilized.

The beam path is as shown in Fig. 2. The radiation of the laser-diode array (9.1) of the lowest plane, i.e., the right, lower laser-diode array (9.1) in Fig. 1, is directed at the hypotenuse sides (7), which serves as a mirrored deflection surface (6) of the first prism plate (1) lying across from it and is deflected through 90° so that the ray bundle (4) is redirected into the principal beam direction, indicated by the arrow (13). In the next plane above this as seen in the y-direction, the next laser-diode array (9.2) is positioned, which radiates into the facing (12) of the rectangular plate (2), whereby the laser beam exits from the opposite facing (14), i.e., the laser radiation of this laser-diode array is sent without deflection directly into the direction of the principal beam direction (13). In the next higher plane, the laser-diode array (9.3) on the left in Fig. 2 is positioned, which radiates toward the hypotenuse sides (7) of the second prism plate (3). As with the first prism plate (1), this beam is redirected on the mirrored surface or deflection surface (6), based on the incidence an angle of 45°, into the direction of the principal beam direction (13), i.e., through 90°. With respect to the next plane, which lies above the second prism plate (3), the sequence of the arrangement of the first prism plate (1), the rectangular plate (2) as well as the second prism plate (3) is repeated so that, seen from the direction of the

perspective arrow II in Fig. 2, the construction is achieved as presented in Fig. 1. All of the radiation (4) can be further reshaped, e.g., collimated, by the additional lens (27).

Due to the collimation optics (11) associated with each laser-diode array (9.1, 9.2 and 9.3), the radiation of the individual laser-diode arrays, which are strongly divergent in the y-direction, can be directed practically parallel onto the deflection surfaces (6) so that the cover surfaces of each element lying above and below assume essentially no function in the beam guidance. In the case where the divergence of the laser beam after the imaging optic (11) is still large enough that the cover surfaces are struck by the radiation, the cover surfaces can also serve as additional beam guides. Depending upon the embodiment, the plate elements can also be utilized as mounting supports or as application surfaces for the cooling body (10) of the laser-diode array (9) or for the imaging optics, for which they can be appropriately lengthened and shaped.

Since the prism plates (1, 3) and the rectangular plate (2) under one another each have the same dimensions or edge lengths, several of these arrangements can be machined simultaneously, such as, for example, by optical polishing of the prism edges or of the deflection surfaces. During construction of the plate stack, appropriate spacing elements, which are not shown, can be included, which then act as supports for the plates lying above or below. For example, two prism plates can also be cemented with the prism edges against one another, whereby one plate then serves as the prism plate that has the deflection surface (6) while the other prism plate is utilized as spacing element. In this arrangement, in contrast to the arrangements in Fig. 1 and 2, radiation enters into the side of the one prism plate and the beam is guided in this prism plate up to the corresponding deflection surface. Here, by an appropriately thin layering of the cover surfaces of the plate elements, for example, with a medium with a lower refractive index than that of the plate medium, it can be avoided that radiation penetrates into the neighboring plate elements.

The rectangular plates (2), as illustrated above using the embodiments of Fig. 1 and 2, can be omitted if the parallel alignment can be achieved by other means using appropriate spacing elements between the prism plates (1, 2). In such a case, instead of the rectangular plate (2), a free space or intermediate space is left through which the laser radiation of the laser-diode array assigned to this plane, for example, the laser-diode array (9.2), passes in the ambient medium (e.g., air) without a further optical element having to be assigned in this beam region.

In a further, second embodiment, which is represented in Fig. 3 and 4, instead of a stack of individual prism plates (1, 3) and, as the case may be, rectangular plates (2), a single prism (15) can be used, in the case of Fig. 3, a right-triangular prism with two long, equal legs (16, 17). The legs (16, 17) are, with respect to the individual planes, coated in alternating order antireflective (presented in Fig. 4 designated by AR or unhatched) and highly reflective (presented hatched in the figures, designated by HR).

The hypotenuse sides (18) of the individual prism plates (15) are coated antireflective (AR) at all levels. Coupling prism plates (19 and 20), which are assigned to each of the leg sides (16 and 17) of the individual prism's (15), serve the purpose of passing the radiation of the respective laser-diode arrays (29.2 and 29.1) into the prism (15) without beam deflection. The beam path for this arrangement, in accordance with Fig. 3 and 4, with respect to the laser-diode arrays (29.1, 29.2 and 29.3) is as follows. The radiation of the upper laser-diode array (29.1 in Fig. 3) first passes through the coupling prism plate (20) without deflection and enters the prism (15) through an antireflective coated strip on the leg (16) and is redirected by a highly reflective coated strip on the opposite leg (17) toward the hypotenuse (18) where the laser beam (4) exits. The radiation of the second laser-diode stack (29.2), presented lower left in Fig. 3, which is positioned in the next following plane, first passes through the coupling prism (19) and then enters through the antireflective coated leg (17) and passes through the prism (15) without deflection so that the beam exits from the

hypotenuse (18). The radiation of the third laser-diode array (29.3), positioned on the hypotenuse side (18) of the prism (15) in Fig. 3, which is positioned in the plane that follows the plane corresponding to the upper prism (10), enters into the hypotenuse side (18) of the prism (15) of this plane, is then deflected by the highly reflective coated leg (16) of this prism so that it strikes the second leg (17), which likewise has a highly reflective coating, so that the beam is then further directed to the hypotenuse side (18) and exits there in the principal beam direction.

The sequence of the arrangement of the individual laser-diode arrays (29.1, 29.2 and 29.3) with respect to the individual plans and the corresponding coatings of the legs (16, 17) as well as of the hypotenuse (18) of the prism (15) for each plane is repeated just as explained above and shown in Fig. 4, whereby the sequence of planes of the base unit is repeated in the y-direction. The advantages of this embodiment are the increased stability and the simple manufacturing of the prisms, which have larger dimensions relative to the individual prism plates that were illustrated using the embodiment of Fig. 1 and 2 since, because of repetition in the type of coating, and mainly highly reflective, the prism plates of two neighboring planes can be combined. However, a single prism block can also be prepared that has an extension in the y-direction that corresponds to the entire height of all planes of the stack, whereby the individual legs (16, 17) as well as they hypotenuse (18) can then be coated as shown in Fig. 4.

A third embodiment is presented in Fig. 5 and 6. This arrangement corresponds in principle with the arrangement that is presented in Fig. 3 and 4 except that the individual prisms (15, 19 and 20) are replaced by one prism block (21), which in its geometry corresponds to the two further prisms (19 and 20) of Fig. 3. The respective long sides, i.e., the hypotenuse sides (22, 23) of the prism-block sections (24, 25) of the prism block (21) serve as deflection surfaces. These hypotenuse sides (22, 23) are made highly reflective (HR, presented hatched in Fig. 6). At the places at which the laser-diode beam of the

corresponding plane is to pass without deflection, free spaces or cutouts (26) are once again left (presented unhatched) as shown in Fig. 6. Each unit is constructed from three laser-diode arrays (39.1, 39.2 and 39.3) each of which is oriented in one of three sequential planes (x-z-plane). In the first plane, for example, beginning with the laser-diode array (39.2), lower left in Fig. 5, a free space (26) is present so that the beam is directed through this free space (26) directly in the principal beam direction (13). In the next plane, to which the laser-diode array (39.1) on the upper edge of the prism-block section (25) is assigned, it runs likewise through a free space (26) then strikes the mirrored hypotenuse (22) of the prism-block section (24) and there, impinging at an angle of 45°, is redirected into the principal beam direction (13). In the plane following after this, is then found the laser-diode array (39.3), which can be seen on the right side of the arrangement in Fig. 5, whose radiation then strikes the mirrored surface or hypotenuse (23) of the prism-block section (25), from there is deflected off the hypotenuse (22) of the other prism-block section (24) where it is then further redirected into the principal beam direction (13). The sequence of the planes repeats itself in accordance with the sequence described above of the unit as regards the individual planes that follow above or below in the y-direction.

Consequently, the cooling bodies (10) or the laser-diode arrays (39.1, 39.2 and 39.3) mounted on them can be stacked and thereby shaped just as was illustrated in the context of the first embodiment using Fig. 1.

With the arrangements described above, the separation of the laser diodes, designated with h_{DL} in Fig. 1, and thereby the height of the heat sinks can be chosen to be larger than with a linear stacking arrangement for which the individual laser-diode arrays (9) are oriented in a constant orientation relative to the x-z-plane. This enables the implementation of heat sinks with better mechanical and cooling characteristics as well as a simpler production and mounting. In addition, the laser-diode stack can be constructed with greater positioning precision of the laser diodes, namely, in comparison to linear stacking arrangements. The prism and rectangular plates can be positioned very tightly

on one another with small separation, a (see Fig. 1). In this way, the gaps in the beam distribution are reduced in an imaging plane where the radiation (4) seen in the direction of the principal beam direction (13) is brought together. The allowable tolerances for the dimension of the imaging optics are decreased since their separation from one another in a laser-diode stack is increased by about a factor of 3, equivalent to the contribution of the plane of one unit.

The output beam of the entire arrangement, because of the special beam summation, exhibits, besides higher beam output, also a higher symmetry in comparison to the strongly asymmetric beam distribution of the individual laser diodes or also in comparison to the beam distribution of linear stacking arrangements. This is advantageous for applications that have an extensively symmetric geometry. Examples are the use of laser-diode radiation for optical pumping of solid-state lasers, in particular longitudinal pumping along the laser-beam axis and for applications in material processing. The conformity of the beam distribution enables, for example, in optical pumping, a higher effectiveness of laser-beam generation or, in material processing, a higher efficiency of the employed laser output.

The higher beam symmetry is also advantageous in further beam forming, which can then be carried out with simpler rotation-symmetric elements (for example, ordinary lenses). In the case of the linear stacking arrangement, for rotation-symmetric elements, larger element diameters (for example, lens diameters) are necessary, which leads to greater imaging errors and causes higher costs.

Claims

1. Arrangement for shaping and redirecting radiation from at least n linear laser-diode arrays whose beam-emission apertures run in the direction lying in the x-z-plane and whose ray bundles are directed in the x-z-plane using

imaging optics and are redirected by optical elements under a specified beam angle whereby m optical elements are stacked in planes on top of one another in the y-direction forming a unit whereby the x-, y- and z-directions constitute an orthogonal coordinate system and n, m are positive integers, characterized in that at least m = (n-l) of the optical elements (1, 3, 6; 15, 16, 17; 22, 23, 24, 25) are provided, where $n \geq 3$ and l is the integral part of the quotient n/k, whose deflection surfaces (6; 16, 17; 22, 23), when projected on a common plane in the x-z-plane, are oriented at an angle to one another, that the three or more laser-diode arrays (9.1, 9.2, 9.3; 29.1, 29.2, 29.3) stacked in consecutive planes in the y-direction are combined into a unit of k laser-diode arrays where k is a positive integer and $3 \leq k \leq n$ and whereby the first optical element (1, 6; 15, 17; 22, 24) is assigned to the first laser-diode array of the unit (9.1; 29.1; 39.1), the second optical element of the unit (3, 6; 15, 16, 17; 22, 23, 24, 25) is assigned to the second laser-diode array (9.3; 29.3; 39.3) and so forth until the (k-1)'st optical element is assigned to the (k-1)'st laser-diode array and the elements (1, 3, 6; 15, 16, 17; 22, 23, 24, 25) deflect the beams on the deflection surfaces (6; 16, 17; 22, 23) into an essentially common beam direction (13) and the k'th laser-diode array (9.2; 29.2; 39.2) radiates directly or undeflected through a further optical element in the final beam direction (13) so that the beam segments, at least in one imaging plane, are combined into an essentially common beam direction and that the sequence of planes, as regards the ordering of the respective laser-diode arrays (9.1, 9.2,9.3; 29.1, 29.2, 29.3; 39.1,39.2,39.3) and their associated respective optical elements (1, 3, 6; 15, 16, 17; 22, 23, 24, 25) in the y-direction above and/or below the unit by more than k planes, recapitulates the sequence of the plans of the unit.

2. Arrangement according to Claim 1, characterized in that the deflection surfaces (6; 16, 17; 23, 22) are formed from the edges of prism plates (1, 3; 15; 24, 25).

3. Arrangement according to Claim 2, characterized in that the prism plates (1, 3; 15; 24, 25) have the form of a right triangle in the x-z-plane.

4. Arrangement according to Claim 1, characterized in that the surfaces (6; 16, 17; 22, 23) that redirect the radiation are formed as mirrored surfaces.

5. Arrangement for shaping and redirecting radiation according to one of the Claims 1 through 4, characterized in that the radiation of the k'th laser-diode array (9.2; 29.2; 39.2) passes through a free space (26) between two neighboring optical elements.

6. Arrangement according to Claim 1, characterized in that the radiation of the k'th laser-diode array (9.2; 29.2; 39.2) passes through a rectangular plate (2).

7. Arrangement according to Claim 4, characterized in that the optical elements (1, 3, 6; 15, 16, 17; 22, 23, 24, 25) are formed from one block and the free spaces by appropriate cutouts in the block.

8. Arrangement according to Claim 1, characterized in that the optical elements (1, 3, 6; 15, 16, 17; 22, 23, 24, 25) are each formed from one or several blocks and the radiation of the k'th laser-diode arrays (9.2; 29.2; 39.2) passes without deflection through a transparent region.

9. Arrangement according to Claim 1,characterized in that the deflection surfaces (6; 16, 17; 22, 23) are oriented at an angle of approximately 90° to one another.

3 page(s) of figures are appended

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(54) Laser wafer and method for its fabrication.

(57) A laser wafer contains a facet (F) integrated into the wafer and positioned across from the laser system (AF, AZ) that serves as a concave mirror for focusing the diverging light emerging from the laser system. The facet (F) is fabricated by etching out a cavity (V) in the semiconductor substrate (S) using a dry-etching process. A two-dimensional curvature of the cavity wall across from the laser system and constituting the facet is achieved in that the curvature in one dimension is presented by the shape of the cutout bordering the cavity in one of the photo-enameling masks shielding the substrate surface and in the other dimension by oblique ion incidence during dry etching.

LASER WAFER AND METHOD FOR ITS FABRICATION

The invention relates to a laser wafer according to the introductory clause of Patent Claim 1 as well as a method for its fabrication.

From a paper by Z.L. Liau and J.N. Walpole in Appl. Phys. Lett. 46(2), 15 Jan. 1985, a laser wafer of this type is known in the art.

In this laser wafer, the cavity in the semiconductor laminate that is to make possible the orthogonal emission of light is produced by the stepwise etching out of semiconductor material. It has the form of a trench whose wall across from the laser system is curved in a plane orthogonal to the longitudinal direction of the trench but runs straight along the longitudinal direction of the trench. This one-dimensionally curved wall is not able to focus laser light diverging along the longitudinal direction of the trench. In order to be able to focus of laser light emerging orthogonal to the surface of the semiconductor laminate onto a narrowly restricted region, e.g. the entrance surface of an optical fiber, an additional optical component is then required, which must be especially fabricated and connected to the laser wafer with precise adjustment.

The invention is based on the task of making available a laser wafer of the type mentioned above that has all the necessary means for beam focusing integrated into it.

Such a laser wafer is described by the characteristics of Patent Claim 1 and a method for its fabrication by the characteristics of Patent Claim 2.

With the two-dimensionally curved, facet-like wall of the cavity across from the laser system, the initially diverging laser light emerging from the laser system is not only redirected into the direction orthogonal to the lamination planes of the semiconductor laminate but is also focused concentrically to the central beam axis so that all of the laser light redirected by the facet surface is distributed within a narrowly restricted focal spot of a focal plane parallel to the semiconductor surface or else emerges from the cavity produced in the semiconductor as essentially parallel light rays.

The method described in Patent Claim 2 allows the fabrication of the facets in a way that is quite simple in comparison to the stepwise etching method used in the state of the art.

Whereas, with stepwise etching, the etching steps must be followed by heating phases in which the steps produced by the etching are deformed by material migration, the facets can be worked out in a single operation with the dry-etching process used in Patent Claim 2. Finally, vapor-plating, as is, e.g., required in the embodiments described in Subclaims 3, 4 and 7, can be carried out in the same dry-etching enclosure or enclosure in which the dry etching takes place.

Modifications of the laser wafer according to the invention are presented in Subclaims 3 through 6.

By mirroring the facets (subject of Claim 3), as complete a reflection as possible of the generated laser light in the direction orthogonal to the lamination plane of the semiconductor is achieved.

If a monitor diode (Claim 3) is produced in the laminate on the side of the cavity opposite from the laser system, which can occur simultaneously with the fabrication of the laser system, the mirroring of the facet must allow a portion of the laser light to pass through, which can be achieved by an appropriately thin mirroring, e.g., with a gold layer. In addition, before the mirroring, the facet surface must be insulated, e.g., with a SiO_2 layer, from the metallic reflecting layer in order to avoid a short-circuit of the active layers of the monitor diodes by the electrically conductive mirroring.

Claims 5 and 6 are concerned with the curvature of the facet surfaces, which can be formed according to Claim 5 as part of a paraboloid surface, according to Claim 6 as part of an ellipsoid surface. If the facet surface is positioned in such a way that the emission surface of the laser system lies approximately in the focal point of the paraboloid or one of the focal points of the ellipsoid, then the laser wafer would emit approximately parallel directed light for parabolic facet surfaces and light converging onto a focal point for elliptic facet surfaces.

Claim 7, finally, describes the method according to Claim 2 for the case that, according to Claim 4, monitor diodes are present.

An embodiment of the laser wafer according to the invention as well as a method for its fabrication will now be shown in the following with the aid of 5 figures.

In these are shown:

Fig. 1a and b: a laser wafer according to the state of the art,

Fig. 2: the principle of the laser wafer according to the invention,

Fig. 3: a semiconductor wafer with photo-enameling mask before dry etching,

Fig. 4: a diagram of the dry-etching process,

Fig. 5: section through a wafer with laser system according to the invention and integrated monitor diode,

In Fig. 1a, a sectional drawing of a laser wafer according to the state of the art is represented. In a semiconductor laminate (substrate S), in which a laser system (L) is created in the region of the separation surface of p-type semiconductor material (p) and n-type semiconductor material (n), a cavity (V) is etched whose wall on the laser side is formed essentially vertical and whose wall opposite from the laser system curves concave outward from the laser system and acts as a concave mirror (SP) that deflects the diverging light beam emerging from the laser through 90° and focuses it on to a focal point (B).

In Fig. 1b, which shows the substrate in relief, it can be seen that the curvature of the wall of the cavity across from the laser system exists in only one dimension so that the focal point (B) represented in Fig. 1a, which appears in a plane orthogonal to the longitudinal axis of the cavity, upon changing to a relief view, is transformed into a focal line (BL), whereby a focusing of the laser light in a plane parallel to the longitudinal axis of the cavity does not occur.

For the laser wafer according to the invention, whose principle is presented in Fig. 2, a two-dimensional curved facet (F) in the wall of the cavity across from a laser system is located across from each light-emission surface (AF) of the laser system created in active zones (AZ) of the substrate (S). The divergent laser light emitted from the laser system is focused by the surface of the facet (F) onto a focal point (P). The focal area through which all of the light reflected by the surface of the facet passes in the region of the focal point (P) is, under favorable conditions, so small that a virtually loss-free coupling of the laser light into an optical fiber is possible without additional optical components. For this, the facet surface must be part of an ellipsoid surface in one of whose focal points the emission surface of the laser is located. If, instead of an ellipsoid surface, a paraboloid surface is created, then the laser light would emerge from the cavity (V) as essentially parallel.

In order to fabricate a laser wafer according to the invention, a substrate (S), created using known methods, with laser systems laid down in active zones (AZ) is laminated with photo-enameling and is exposed with appropriate enameling masks in such a way that the structure represented in Fig. 3 arises. In the photo-enameling fields (PH) masking the individual laser domains, cutouts (FA) are provided that determine the curvature of the facets, which are etched out later, in planes parallel to the longitudinal axes of the cavities between the laser domains.

To etch the cavities including the facets, the substrate (S) provided with the photo-enameling masks is exposed in a reaction chamber to an ion beam, which comes from a source (Q) (Fig. 4) and strikes the substrate surface at variable angles of incidence. The substrate, as presented in Fig. 4, is arranged so it can turn, e.g., around the normal (X) to the surface and swivel on a horizontal axis (Y). The intensity and configuration of the ion beam as well as the exposure time of the substrate in positions appropriate for producing a desired facet curvature are likewise variable during the dry-etching process.

The mirroring of the facet surface is carried out upon completion of the etching, e.g., in the same reaction chamber. If an insulation layer underlying the mirroring is necessary in order to avoid a short-circuit of one of the monitor diodes located across from the laser system due to the metallic layer of the mirror, the insulation layer (e.g., SiO_2) can be applied in the same reaction vessel.

In Fig. 5, a section through a substrate (S) perpendicular to be longitudinal direction of the cavities (V1, V2) is represented. Two laser systems (L1, L2) with opposing monitor diodes (M1, M2) each emit their light in the direction of the walls of the provided cavities formed as facets. The two-dimensionally curved facet surfaces have a semitransparent mirror layer (SP) underlaid with an insulation layer (IS). After fabrication of the laser wafers, the substrate (S) is split along the separation surfaces (TF).

Claims

1. Laser wafer with at least one laser system embedded in a semiconductor laminate and emitting beams parallel to the laminations each with a cavity etched into the laminate and located in the laser path whose wall lying on the side of the laser system is primarily flat and oriented orthogonal to the laser

beam and whose wall located across from the laser system is curved concave away from the laser and is inclined relative to be laser beam direction in such a way that the part of the laser light reflected by the surface of the wall emerges from the cavity on average orthogonal to the laminations, characterized in that the wall of the cavity (V) located across from the laser system (L, L1, L2) is curved two-dimensionally and forms at least one facet (F) that works as a concave mirror and as such focuses the laser beam.

2. Method for fabrication of the laser wafer according to Claim 1, characterized in that, after construction of the semiconductor laminate (substrate S) with the laser systems (L1, L2) embedded in them, a photo-enameling mask (PH) is created on the surface of the laminate using known methods whereby, at the locations where cavities (V1, V2) are to be etched into the laminate, the mask has cutouts (FA) whose edge away from the laser is curved concave away from the laser along the surface of the laminate in accordance with the curvature of the facet (F) to be created in each cavity so that the laminate is dry-etched under oblique ion incidence in the region of the cavity to be produced whereby the angle of incidence of the ion beam is varied in two mutually orthogonal planes during the dry-etching in such a way that, in the region of the cutouts (FA) of the photo-enameling masks, the desired two-dimensionally curved facet surfaces are formed.
3. Laser wafer according to Claim 1, characterized in that the surface (SP) of the facet located across from the laser system (L2) is mirrored.
4. Laser wafer according to Claim 2, characterized in that a monitor diode (M2) is formed in the laminate (substrate S) on the side of the cavity (V2) opposite from the laser system (L2) and that the mirroring (SP) applied to the facet located across from the laser system is partially transparent and is electrically separated from the monitor diode (M2) system by an underlaid insulation layer (IS) or is itself an insulator.
5. Laser wafer according to Claim 1, 3 or 4, characterized in that the facet located across from the laser system is part of the surface of a paraboloid in whose focal point the emission surface (AF) of the laser system is located.

6. Laser wafer according to Claim 1, 3 or 4, characterized in that the facet located across from the laser system is part of the surface of a key ellipsoid in one of whose focal point the emission surface (AF) of the laser system is located.
7. Method according to Claim 2, characterized in that, during the construction of the semiconductor laminate (substrate S) with the laser systems (L1, L2) embedded therein, monitor diodes (M1, M2) are produced that lie across from the laser systems and have the surface of a concave mirror and that, in order to produce a partial reflection, before the application of a semitransparent layer, an electrically insulating layer (IS) is applied if the semitransparent layer is not itself insulating.